Title of the Invention

A METHOD FOR MEASURING THREE DIMENSIONAL SHAPE OF A FINE PATTERN

Background of the Invention

The present invention relates to a method for measuring a three dimensional shape of a fine pattern formed on a semiconductor device such as a semiconductor memory or integrated circuit.

SEMs (scanning electron microscope) are used for measuring fine patterns formed on semiconductor devices. The SEM obtains an electron beam image of a sample obtained by detecting the secondary electrons and reflected electrons generated when an electron beam is irradiated onto the sample. The most popular SEM in semiconductor processing is called a critical dimension SEM, which measures a sample mainly by using a secondary electron beam image.

Fig. 2 shows relationship between a cross sectional shape and secondary electron beam image of a sample. The greater a slope of the sample, the greater strength of secondary electrons, so that, as shown in Fig. 2, the image having bright portions(hereinafter called bright bands) corresponding to edge portions (slope portions) of the sample pattern and dark portions corresponding to plane portions of the sample pattern is obtained. With the bright bands, d1 and d2 are measured to obtain a bottom size and top size of the sample, respectively. However, three dimensional information such as a height of the sample and a slope angle of the edge cannot be obtained.

In the semiconductor processing, the critical dimension SEM has been conventionally used for optimizing the conditions of a

manufacturing machine such as an aligner and etcher or for monitoring process fluctuation. However, with fining of the patterns, three dimensional shapes of the samples need to be measured in various cases, where the critical dimension SEM is not always useful.

Related arts for measuring cross sectional shapes are as follows.

(1) After a wafer is cut or FIB-processed, a cut surface of the wafer is observed using an electron microscope.

(2) The cross sectional shapes are observed using an AFM (Atom Force Microscope).

(3) The cross sectional shapes are observed using scatterometry.

In these methods, there are the following problems.

In the method of (1), it takes long time to prepare for the observation of the cross sections. Additionally, the cut or FIB-processed wafers are contaminated, and thus cannot be completed as products. As a result, this method cannot be used for the process fluctuation monitoring in a quantity production process.

In the method of (2), it does not take longer time than that in the method of (1) to observe the cross sections. However, the AFM has low throughput, which is about 1/3 of that of the popular critical dimension SEM, and cannot measure all the patterns because of restriction of the chip shapes. Consequently, as it is near-meaningless, critical points cannot be measured in the process fluctuation in which measurement of three dimensional shapes is required.

Recently, the scatterometry of (3) is receiving attention, because it can operate at high speed and measure cross sectional shapes non-destructively. Using the fact that spectral distribution of scattered light from a sample changes depending on a material and cross sectional

shape of the sample, the scatterometry matches the spectral distribution of the actually-measured sample to the spectral distribution library of various cross sectional shape models previously produced using offline simulations thereby to indirectly measure a cross sectional shape of the sample (see Fig. 3). In principle, any pattern shape can be produced. However, current computers cannot generate a library having variations of all patterns. In the present condition, only lines and space patterns uniformly repeated in one direction are measurable. As a result, the scatterometry is used only for measuring test-specific patterns formed on a wafer, and cannot measure arbitrary patterns (for example, critical points for process fluctuation).

The arts related to the present invention are disclosed in JP-A No.141544/1991, JP-A No.342942/1992, and JP-A No.506217/2002.

These related arts have the following problems. The critical dimension SEM, which is popular in the semiconductor processing, can measure plane shapes by use of electron beam images of arbitrary patterns, but cannot measure three dimensional shapes. The scatterometry can measure three dimensional shapes, but the sample patterns are limited to lines and spaces. Therefore, the scatterometry can measure only the test patterns produced for measurement.

Summary of the Invention

The present invention provides a method for measuring a three dimensional shape of an arbitrary fine pattern formed on a semiconductor device, in other words, a method for measuring a three dimensional shape not limited to a test pattern.

In the present invention, an optical measurement system such as

scatterometry measures cross sectional shape information about a test pattern, an electron microscope obtains an electron beam image of a fine pattern, and plane surface information about the fine pattern is obtained from the electron beam image and is combined with the cross sectional shape information about the test pattern to measure a three dimensional shape of the fine pattern.

Additionally, in the present invention, an optical measurement system such as scatterometry measures cross sectional shape information about a test pattern, an electron microscope obtains an electron beam image of an arbitrary pattern, and the cross sectional shape information about the test pattern is applied to slope change information about a surface of the fine pattern reflected on the electron beam image to measure a three dimensional shape of the fine pattern.

Further, in the present invention, an optical measurement system such as scatterometry measures cross sectional shape information about a test pattern, an electron microscope also obtains an electron beam image of a test pattern, a relational equation is derived from the cross sectional shape information and the electron beam image, and the relational equation is applied to an electron beam image of a fine pattern to measure a three dimensional shape of the fine pattern.

Further, in the present invention, cross sectional shape information about a test pattern is obtained by an optical measurement system such as scatterometry, and used as a constraint for calculating a three dimensional shape of a fine pattern through the following methods (1) and (2).

(1) With a plurality of the images when a fine pattern tilts at different angles, which images are obtained by an electron microscope

having a beam tilt or stage tilt system, a three dimensional shape of the fine pattern is measured on the principle of triangulation.

(2) With a plurality of reflected electron beam images obtained by a plurality of reflected electron detectors, a three dimensional shape of a fine pattern is measured on the principle of photometric stereo.

These and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

Brief Description of the Drawings

Fig. 1 is a procedure of measurement in a first embodiment of the present invention.

Fig. 2 shows a cross sectional shape of a measurement sample and a secondary electron beam image thereof, where measurement by a conventional critical dimension SEM is explained.

Fig. 3 is a schematic diagram showing a system of scatterometry.

Fig. 4 shows the first embodiment of the present invention.

Fig. 4(a) shows a cross sectional shape of a pattern.

Fig. 4(b) shows a signal waveform of a SEM image signal of the pattern of (a).

Fig. 4(c) shows a first-order differentiation waveform obtained by calculating a first-order differentiation of the signal waveform of (b).

Fig. 5 shows the first embodiment of the present invention.

Fig. 5(a) shows a cross sectional shape of a pattern.

Fig. 5(b) shows a signal waveform of a SEM image signal of the pattern of (a).

Fig. 5(c) shows a method for calculating a three dimensional shape of a sample from a secondary electron signal strength of a sample.

Fig. 6 is a procedure of measurement of a second embodiment of the present invention.

Fig. 7 shows the principle of stereoscopic in the second embodiment of the present invention.

Fig. 8 shows a procedure of measurement in a third embodiment of the present invention.

Fig. 9 shows the principle of the third embodiment of the present invention.

Fig. 10 is a block diagram showing how a method for measuring a three dimensional shape according to the present invention is used in a semiconductor processing line.

Fig. 11 is a flowchart of a procedure of measuring a three dimensional shape according to the present invention.

Fig. 12 is an elevation of a screen displaying a result of measurement in the second embodiment of the present invention.

Fig. 13 is an elevation of a screen displaying a result of measurement in the third embodiment of the present invention.

Description of the Preferred Embodiments

The present invention is explained below with reference to the appended drawings.

[First embodiment]

Fig. 1 shows a first embodiment of the present invention.

A large number of semiconductor chips 201 are formed on a wafer 100. A scribe area 204 is formed between the semiconductor chips 201.

The scribe area 204 is cut to complete the semiconductor chips. A test pattern 202 is formed on the scribe area 204. The test pattern 202 is formed in the same manufacturing process as a device pattern 203 in the semiconductor chips 201. In other words, materials of the test pattern 202 and device pattern 203 are the same, and their film thicknesses are almost the same.

As shown in Fig. 1, an electron beam image of a required portion of the scribe area 204 is obtained by a SEM, and the test pattern 202 is measured by scatterometry.

Fig. 11 is a flowchart showing a procedure of measurement. A line width Wn and bright band width En of an electron beam image are measured, where n represents a measurement position in the y direction on the image. As shown in Fig. 1, with a film thickness h, which is a piece of cross sectional shape information about the test pattern, which information is obtained by the scatterometry, a tilt angle θn at the measurement position n is determined when the cross section is considered as a trapezoid.

Actually, as shown in Fig. 4(a), the cross section is not a trapezoid, but has, for example, a bottom roundness edge and top roundness. In such a case, a first-order differentiation waveform as shown in Fig. 4(c) is obtained from an electron beam image signal (shown in Fig. 4(b)) of a device pattern, which signal is detected by the SEM, to quantify the average slope angle ($\tan^{-1}$(H/E), where H is a height when the cross section is considered as a trapezoid and E is a width between the top and bottom of the slope when viewed from above the pattern), a ratio of the bottom roundness (B/H, where, in the first-order differentiation waveform, B is a width between the rising point corresponding to the

bottom and the maximum point), a ratio of the top roundness (T/H, where, in the first-order differentiation waveform, T is a distance between the minimum point and the starting point of the flat portion corresponding to the top), and so on. Then, a shape of the pattern may be judged.

Fig. 5(b) shows a signal waveform of an electron beam image of a sample having a cross sectional shape as shown in Fig. 5(a). A signal strength SE_i of each point i on the slope is proportional to $1/\cos\theta i$ (relationship of an equation 5.1 of Fig. 5)(θi is a tilt angle of a sample). Therefore, the cross sectional shape may be determined as follows.

The equation 5.1 of Fig. 5 has two unknowns *a* and *b*. The cross sectional shape may be determined through the following procedure. The unknowns *a* and *b* are determined thorugh, e.g., a least-squares method so that a result of integrating $\tan\theta i$ ($i=0$ to N) becomes a film thickness H (relationship of an equation 5.2 of Fig. 5, where d is 1/N times of a width between a top and bottom of an slope surface corresponding to E of Fig. 4), and substituted for the equation 5.1 of Fig. 5.

[Second Embodiment]

Fig. 6 shows a second embodiment of the present invention.

In the present embodiment, on the principle of stereoscopic, a three dimensional shape of a sample is obtained from a plurality of images of the sample whose tilt angle changes by an electron microscope having a beam tilt or stage tilt system. Fig. 7(a) is the electron beam image when a tilt angle of the sample is $\alpha 1$, and 7(b) is the electron beam image when a tilt angle of the sample is $\alpha 2$. As shown in Figs. 7(c) and 7(d), because a width of the edge, when viewed from vertically above the sample, changes depending on the tilt angle, widths of the bright bands

of Figs. 7(a) and 7(b) are different.

The bright band widths E1 and E2 of the images are measured to determine a tilt angle θ of the edge. The tilt angle θ is substituted for an equation 7.2 of Fig. 7 to determine a height H0. The widths E1 and E2 change depending on the measurement points of an actual sample. It is thus necessary to determine which point on Fig. 7(b) corresponds to the measurement point of the bright band width of Fig. 7(a). However, for example, when a surface of the sample is smooth, it is difficult to correctly determine the corresponding point. In this case, information about a film thickness *h* obtained by the scatterometry can be used. Instead of determining the corresponding point, a plurality of candidate points are previously determined, and heights of the candidate points are determined by the equation 7.2 to exclude the candidate points having heights different from the film thickness h.

In Fig. 7, only a starting point and ending point of the edge are used as the corresponding points. When there are distinguishing points also in the way of the edge due to, e.g., irregularities of the surface of the sample, the distinguishing points may be added as the corresponding points. The three dimensional shape obtained by the above-described method is useful also for grasping condition of three dimensional edge roughness.

[Third Embodiment]

Fig. 8 shows a third embodiment of the present invention.

In this embodiment, on the principle of photometric stereo as shown in Fig. 9, a three dimensional shape of a sample is obtained from left and right reflected electron beam images (two left and right reflected electron beam images are simultaneously obtained by two right and left

reflected electron beam detectors). Figs. 9(a) and 9(b) show images and waveforms obtained by the left and right reflected electron beam detectors. In Fig. 9(a), the left edge portion is brighter, and the shadowed right edge portion is darker. In Fig. 9(b), the left edge is darker, and the shadowed right edge is brighter.

In an equation 9.1, K needs to be experimentally determined by measuring signal strengths A and B of a sample having a known slope angle θ. In this embodiment, a test pattern is measured by both the scatterometry and SEM, θ is determined from a result of measurement of the scatterometry, and the signal strengths A and B are substituted for the equation 9.1 to determine K. Once K is determined, a cross sectional shape can be determined from signal strengths of reflected electron beam images of an arbitrary pattern. In the second embodiment, it is necessary to search the corresponding points. In this embodiment, reflected electrons are simultaneously obtained by the two right and left reflected electron beam detectors, so that two images of the same point are obtained. As a result, it is not necessary to search the corresponding points.

An actual cross sectional shape is not a trapezoid as shown in Fig. 9(c), but has a constantly-changing slope angle as shown in Fig. 9(e). Also in this case, K is previously determined by measuring a test pattern by means of the scatterometry and SEM, and a slope angle θi of each point may be determined by an equation 9.3. A height H0 is determined by integrating tan θi. As a result, an arbitrary three dimensional shape can be determined from the right and left reflected electron beam images.

[Usage in Semiconductor Processing]

Fig. 10 shows how a method for measuring a three dimensional

shape according to the present invention is used in semiconductor processing. A scatterometry 110 and a SEM 111 are positioned close to each another, and execute measurement before and after resist exposure/development processing 120 and etching processing 130 by means of a consol 112. The scatterometry 110 and the SEM 111 are connected to, e.g., a recipe server 140, a work record management system 141, and a QC data collection/analysis system 142 via a communication line 150.

With such a system, the scatterometry 110 and the SEM 111 measure three dimensional shapes of resist patterns formed on a wafer through the resist exposure/development processing 120 to monitor the resist exposure/development processing 120.

The scatterometry 110 and the SEM 111 measure three dimensional shapes of semiconductor devices and circuit patterns formed on a wafer through the etching processing 130 to monitor the etching processing 130.

The three dimensional shape measurement data of the resist patterns and that of the element and circuit patterns are transmitted via the communication line 150 to the QC data collection/analysis system 142, where the relationship between both data is analyzed. In accordance with the analysis result and work record data stored in the work record management system 141, resist exposure/development processing and etching processing recipes stored in the recipe server 140 can be controlled.

[Method for Displaying Results]

Figs. 12 and 13 show examples of screens for outputting results of three-dimensionally measuring patterns by means of the scatterometry

110 and the SEM 111.

Fig. 12 shows an example of a display screen of the second embodiment. A SEM image, two types of tilt images, and a result of three dimensional measurement are displayed within one screen. The SEM image shows the area where the two types of tilt images are observed. An electron beam signal waveform within the area is superimposed on the SEM image, and displayed.

This electron beam signal waveform may be a signal waveform for one typical scanning line, for a snmmation of a plurality of scanning lines, or for the combination of all the signal detected in the area where the two types of tilt images are observed (many scanning lines are combined to obtain a waveform having an excellent S/N ratio).

A diagram showing a cross sectional shape of the pattern and shape data of each portion of the cross section are displayed as a result of the three dimensional measurement. When the pattern is formed of a plurality of layers, cross sectional shape data of each layer may be displayed.

Fig. 13 shows an example of a display screen of the third embodiment. A SEM image, two types of tilt images, and a result of three dimensional measurement are displayed within one screen. The SEM image shows the area where the two types of tilt images are observed. An electron beam signal waveform within the area is superimposed on the SEM image, and displayed.

Like in Fig. 12, this electron beam signal waveform may be a signal waveform for one typical scanning line, for a snmmation of a plurality of scanning lines, or for the combination of all the signal detected in the area where the two types of reflected electron beam

images are observed (many scanning lines are combined to obtain a waveform having an excellent a S/N ratio).

A diagram showing a cross sectional shape of the pattern and shape data of each portion of the cross section are displayed as a result of the three dimensional measurement. Cross sectional shape data of each layer may be also displayed. This is because, when the pattern is formed of a plurality of layers, a detection signal changes depending on secondary electron emission efficiency of each layer so that each layer can be recognized to determine the cross sectional shape data of each layer.

As described above, according to the present invention, a three dimensional shape of a fine pattern formed on a semiconductor device such as a semiconductor memory and integrated circuit has been able to be measured more precisely without deconstructing the semiconductor device.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.)